

McGEE SURVEYING CONSULTING

5290 Overpass Road, Ste#107 - Santa Barbara, CA 93111

Telephone 805-964-3520 michael@mcgee.cnc.net

Survey Report for the TO-12 Lidar Mapping Quality Control – Quality Assurance Data Collection for Dewberry & Davis on Lahaina, Lanai & Molokai of the County of Maui, Hawaii

OVERVIEW

Surveyed by: McGee Surveying Consulting (MSC) at 5290 Overpass Rd., Ste#107 Santa Barbara, CA 93111

Survey Method: GPS static, RTK and conventional

Client: Dewberry & Davis Corp. ; **Project. Number:** ____; **Project Name:**

Location: Maui, Lanai & Molokai Islands

City: none ; **County:** Maui; **State:** Hawaii

Attachments: Find the following Documents

- XCL Spreadsheet Listing Control Points with Geodetic Coordinate & Ellipsoid Heights, State Plane Grid Coordinate & Local Tidal Elevations in meters and feet; Points Descriptions, Land Categories
- NGS Data Sheets: HARN Station, CORS and Benchmark Descriptions Referenced in this Survey
- Map: GPS Control Network
- Map: QAQC Points Locations
- Photos of Points

This document serves as a summary report on the above referenced QAQC survey. The purpose of which is to establish ground truthing points for validation of the Lidar measurements and the DEM. Three non-contiguous areas in the County of Maui along the southerly shorelines of Lanai and Molokai and the westerly shoreline of Lahaina, Maui up to 10 meters above sea level. The lidar mapping survey was performed by Airborne 1 Corporation of Los Angeles, California and utilized a laser mounted in an aircraft. The contract required that 60 Fundamental test points be collected, 20 in each of the three areas. Included in this survey are 69 points with photos in six general locations listed on the attached QAQC Point List.

The main concern for the survey is to develop elevations of the QAQC points that would be recoverable and in harmony with existing and future surveys on the Island. There exists sufficient HARN and CORS stations to establish reliable horizontal positions and ellipsoid heights as noted below. What is lacking on the Islands is a vertical orthometric control network in the areas subject to this study.

Circa 2003 the NGS published a leveling network (indicated by published Data Sheets) extending from Kahulie on the east coast of Maui southwesterly to Makena. The actual datum basis for this network is not known; however, four of the Kahulie Tide Station Tidal Benchmarks were included in that survey which allowed for a comparison with the observed mean sea level discussed hereafter. This survey based the vertical datum in part on the work performed by the NGS prior to 2003 using benchmark A6=2008 and checking to the benchmark LUKE HITS in the Isthmus of Maui. On Lanai and Molokai other solutions were used as addressed hereafter.

McGEE SURVEYING CONSULTING

5290 Overpass Road, Ste#107 - Santa Barbara, CA 93111

Telephone 805-964-3520 michael@mcgee.cnc.net

PROJECT DATUMS, REFERENCE SYSTEM

Horizontal Datum: *North American Datum of 1983 (NAD83)(PACP00); Epoch: 2002.00=1993.62 for Hawaii*

Reference Network: *High Accuracy Reference Network (HARN) & CORS*

Vertical Datum: *"Local Tidal" per NGS Data Sheets for Maui and Lanai; and Mean Sea Level (Epoch 1983-2001) for Molokai based on Tide Station Benchmarks (see comments below)*

Reference Network: *NGS Benchmarks in the NSRS and NOAA Tide Station Benchmarks*

Geoid Model: *Geoid 03*

Projection: *Hawaii State Plane Zone 2*

Units for Deliverables: *Feet & Meters*

Notes/Comments: *The horizontal datum in Hawaii and this Pacific Region is consistent with an NAD83 Datum realization for an epoch date of 1993.62 (Aug. 14, 1993) and is designated as NAD83 (PACP00). Quoting from "Introducing Two Spatial Reference Frames for Regions of the Pacific Ocean" by Richard Snay available from the NGS, "users of these frames do not have to cope with changing positional coordinates". Therefore, this survey utilized in the ground monuments published on the 1993.62 Epoch and MAUI CORS published on the 2002.00 Epoch. These positions were agreeable within a few centimeters and compatible with the above definition.*

NETWORK ADJUSTMENTS & ANALYSIS

Network: *This survey was conducted as three separate networks on each Island interconnected by the NGS MAUI CORS and then combined in the following adjustments. The rinex files for the CORS were imported from the NGS with the rapid ephemeris.*

Number of Points in Network: 89

NGS Station Cross References (NGS PID and Names):

Point#	NGS PID	Name	Comments
Maui Control			
2002	TU3102	LAHAINA NW BASE	HARN:
2004	AA3605	JHM R	HARN: at airport
2007	TU3042	LUKE	HARN: Used in 2004 and 2005 Surveys by MSC
2008	TU0201	A6	Benchmark: Used in 2004 and 2005 Surveys by MSC
CORS_MAUI	AJ8470	MAUI	CORS:
	TU0854	LUKE HITS	Benchmark: Used to establish correct Ortho. Ht. on LUKE
Lanai Control			
2202	AA3579	KAUMALAPAU	HARN:
2204	TU3225	LAN2	HARN: Used in 2005 Surveys by MSC
Molokai Control			
2402	AA3590	MKK AP STA B	HARN: at airport
2403		3198 A 2000	Tidal Benchmark by NOAA
2406		3198 C 2000	Tidal Benchmark by NOAA
2407	AA5459	KUMIMI 2 RESET	HARN: GPS but no EH is listed in the Data Sheet

Control Stations: *Existing and new stations established to control this project are points numbered in the 2000+ (Lahaina), 2200+ (Lanai) and 2400+ (Molokai) series*

New Points: *QAQC points established for this project are numbered in the 2100+ (Lahaina), 2300+ (Lanai) and 2500+ (Molokai) series (67 points)*

Station Comments: *NGS HARN station LUKE=2007 was found in 2004 surveys to be in error in the orthometric and ellipsoid heights. In this survey the orthometric height of "LUKE-HITS" a point on the top edge of the standpipe above LUKE was used to transfer an orthometric height down to the brass cap inside a concrete structure (-1.093m). Using this process in the 2005 surveys found the NGS benchmark A6=2008, 13 kilometers southerly, to agree one centimeter.*

Adjustment 1A: *Minimally Constrained/Ellipsoid Height*

Fixed Control: *MAUI (CORS) 2002.00 Epoch was fixed 3D in a Minimally Constrained Adjustment to determine ellipsoid heights and compared with other NGS stations as shown below.*

McGEE SURVEYING CONSULTING

5290 Overpass Road, Ste#107 - Santa Barbara, CA 93111

Telephone 805-964-3520 michael@mcgee.cnc.net

3D/Ellipsoid Heights: Minimally Constrained Adjustment Results:

The adjustment results follow with Coordinate Changes from record to computed in meters.

Station	dN	dE	dZ	Comment
CORS_MAUUI	0.000	0.000	0.000	Fixed 3D
2002	0.011	0.027	-0.102	HARN
2004	-0.014	0.050	-0.122	HARN
2007	0.005	0.006	0.440	HARN
2202	-0.008	0.022	-0.089	HARN
2204	0.002	0.037	-0.081	HARN
1104	0.017	0.015	-0.088	MSC 2005 QAQC Point on Lanai
2402	0.000	0.030	-0.004	HARN
2407	0.010	0.033	0.835	HARN

Notes/Comments: The differences in northing are in good agreement at +/-1cm. The differences in eastings have a small bias of +3cm on average. #2002 and #2004 in the Lahaina area differ vertically by minus 10-12cm but are in relative agreement at 2cm. #2007=LUKE at Kalahaie, Maui, is known to have an incorrect height and the plus 44cm is ignored. #2202, #2204 and #1104 on Lanai differ vertically by minus 8-9cm but are in relative agreement at 1cm and consistent with the #2002 and #2004 in the Lahaina area. #1101 was established from #2204 in November 2005 by MSC. #2402 on Molokai is in good agreement vertically and #2407 does not have a listed ellipsoid height although it is a GPS position.

Adjustment 1B: Minimally Constrained/Orthometric Height

Fixed Control: The MAUI CORS was fixed horizontally and the NGS Benchmark A6=#2008 was fixed vertically in a Minimally Constrained Adjustment to determine orthometric heights and compared with other stations as shown below.

Orthometric Heights: Minimally Constrained Adjustment Determined by Combining the Measured Ellipsoid Height Differences with Geoid 03. In these results, the Height Changes from record to computed are listed in meters.

Point#	dZ	Comment
2002	-0.504	
2004	-0.165	
2007	0.030	LUKE ortho.Ht. per NGS on LUKE HITS Benchmark
2008	0.000	Fixed Benchmark NGS A6
CORS_MAUUI	0.065	
2202	0.037	
2204	-0.038	
1104	-0.053	
2205	-0.051	
2402	0.126	
2403	0.266	
2406	0.279	
2407	0.288	

Notes/Comments: On Maui, #2002 is a HARN station with the orthometric height listed to the nearest meter therefore the difference of 50cm is not significant. #2004 is an airport HARN and the orthometric height is based on a refined geoid model and generally is good for about a decimeter. In this case the difference is 16cm however, this survey is confident because it is in agreement at 1cm with unreported surveys and the closure for this network is 3cm on #2007=LUKE (derived from LUKE HITS). The height of the MAUI CORS for this comparison was taken from the MSC 2005 survey which was based on #2008=A6 and differs 6.5cm in this survey. Since #2204=LAN2, a HARN, was found within 1cm of its MSC 2005 height as noted below, there is an indication that the CORS located on top of Kaleakala Volcano may not be stable.

On Lanai, the difference at #2204=LAN2 HARN is a minus 3.8cm which agrees with the 2005 surveys by MSC that found this to be minus 4.6cm relative to #2008=A6. The difference in height at #2202=Kaunapali HARN station is plus 4cm. The height was taken as 33 feet as listed on the NGS data sheet to the nearest foot. As a matter of information, "BM 33.51" is inscribed into the rock wall adjacent to the point. Also, #2202 is a NOAA Tidal Benchmark and their listed height above mean tide level is 32.89 feet based on about two months of observations in 1932. The estimated rise in sea level would put the elevation now at about 32 1/2 feet. No further analysis was performed. #2205 is

McGEE SURVEYING CONSULTING

5290 Overpass Road, Ste#107 - Santa Barbara, CA 93111

Telephone 805-964-3520 michael@mcgee.cnc.net

a cross on a rock on the jetty on the south side of Manele Harbor pointed out by the contractor on the Harbor improvements. The contractor stated the elevation was 8.56 feet. I assumed this to be based on mean lower low water; therefore, $8.56 - 0.95$ (difference between MLLW and Mean Tide Level at Kaumalpu Tide Station in 1932) = 7.61 feet used here and agreeing by minus 5cm.

On Molokai, #2402 and #2407 are HARN stations with modeled orthometric heights based on GPS. #2402 is listed to the nearest decimeter and #2407 is listed to the nearest meter on the NGS data sheet. The difference of 13cm at #2202 is acceptable and the height at #2407 is not expected to be better than ½ meter. #2403 and #2406 are NOAA Tidal Benchmarks referencing the Kaunakakai Tide Station and were found in relative agreement by 1cm per remote GPS measurements. The difference of 28cm is more than expected and prompted a review of the Local Tidal Datum established by the NGS circa 2003 as a basis for elevations on Maui. Comparison of the published orthometric heights on four NGS Benchmarks at Kahulie that are also NOAA Tidal Benchmarks determined that 0.104 meters must be subtracted from the heights of the NGS Benchmarks to be equivalent to Mean Sea Level based on the present 1983-2001 Tidal Epoch. Subtracting 0.104 meters from the elevation of #2008=A6 improves the differences at #2003 and #2006 to plus 18cm. This is a difference of 18cm over a 100 kilometers distance between Tide Stations. On the Big Island and on Kawai where Tide Stations were connected directly and were space about 100 and 25 kilometers apart, a difference of a few centimeters was found. No further analysis was performed.

As a result of this analysis, The Geodetic Coordinates and State Plane Coordinates were developed from the above 3D minimally constrained adjustment (1A) fixing the MAUI CORS. The orthometric heights were determined in three separate minimally constrained adjustments. At Lahaina on Maui the height of #2008=A6 was held to be consistent with all previous work on that Island, on Lanai the height of #2204=LAN2 was held to be consistent with the MSC 2005 work on that Island, and on Molokai #2406= Tidal Benchmark "3198 C 2000" was held to be consistent with the local determination of Sea Level by the NOAA. See the results below.

Adjustment 1B1 - Lahaina: Minimally Constrained/Orthometric Height

Fixed Control: The NGS Benchmark A6=#2008 was fixed vertically in a Minimally Constrained Adjustment to determine orthometric heights and compared with other stations as shown below.

Orthometric Heights: Minimally Constrained Adjustment Determined by Combining the Measured Ellipsoid Height Differences with Geoid 03. In these results, the Height Changes from record to computed are listed in meters.

Point#	dZ	
2002	-0.504	
2004	-0.165	
2007	0.030	Closure on LUKE
2008	0.000	Fixed A6
CORS_MAUI	0.065	

Adjustment 1B2 - Lanai: Minimally Constrained/Orthometric Height

Fixed Control: The NGS HARN station LAN2=#2204 was fixed vertically in a Minimally Constrained Adjustment to determine orthometric heights and compared with other stations as shown below.

Orthometric Heights: Minimally Constrained Adjustment Determined by Combining the Measured Ellipsoid Height Differences with Geoid 03. In these results, the Height Changes from record to computed are listed in meters.

Point#	dZ	
1104	-0.015	
2202	0.075	
2204	0.000	Fixed LAN2
2205	-0.012	
CORS_MAUI	0.104	

Adjustment 1B3 - Molokai: Minimally Constrained/Orthometric Height

Fixed Control: The NOAA Tidal Benchmark 3198 C 2000=#2406 was fixed vertically in a Minimally Constrained Adjustment to determine orthometric heights and compared with other stations as shown below.

Orthometric Heights: Minimally Constrained Adjustment Determined by Combining the Measured Ellipsoid Height Differences with Geoid 03. In these results, the Height Changes from record to computed are listed in meters.

Point#	dZ	
2402	-0.152	
2403	-0.012	Closure on Tidal BM
2406	0.000	Fixed Tidal BM
2407	0.009	
CORS_MAUI	-0.213	

McGEE SURVEYING CONSULTING

5290 Overpass Road, Ste#107 - Santa Barbara, CA 93111

Telephone 805-964-3520 michael@mcgee.cnc.net

DATA COLLECTION & PROCESSING

Date of Field Surveys: 04/19/2007 to 04/30/2007;

Description: Network Control and QAQC Data Collection were performed by establishing a base receiver and at a secure and protected site while a roving receiver occupied other points in a radial fashion. For static network control the base was moved and the process repeated to create a redundant network. For the QAQC points measured with RTK, the points were re-occupied at a separate time from the same base point for a check. .

GPS Survey Parameters:

Epoch Rate (seconds): 10" for 15-135 minute roving static and 2-8 hours for connections to MAUI CORS. RTK collection was generally 6 measurements at two separate times.

Minimum Satellites: 5 ; **PDOP** ≤ 5 ; **Elevation Mask for Data Collection & Processing (degrees):** 10 & 15

GPS Observables: L1 & L2 Carrier wave, C/A Code and P-Code

Boulder K Index: 1-2

Ephemeris: Rapid for Static Post-Processing

GPS Base Receiver Unit No.: M3, **Operator:** McGee; **Station Identification:** varies

Receiver Make & Model: Leica 530 ; **Antenna Make & Model:** Leica AT502

Antenna Mount: Tripod; **Antenna Height:** varies

GPS Rover Receiver Unit No.: M4, **Operator:** McGee, **Station Identification:** varies

Receiver Make & Model: Leica 530 ; **Antenna Make & Model:** Leica AT502

Antenna Mount: Fixed Pole for static & RTK data collection; **Antenna Height:** 2.085m with some variations

ACCURACY

Vector Residuals: In the minimally constrained adjustment the two dimensional residuals averaging 2-3 cm with a standard deviation of 2 cm. The vertical residuals average 2-3 cm with a standard deviation of 2 cm. Residuals on the RTK points tested against static positions vary up to 2 cm.

Relative Accuracy: On site is expected to be less than 5 cm at 95% Confidence for RTK points. The accuracy of lidar mapping on clearly defined test points is expected to approach 15 centimeters, therefore the test points are at a level of accuracy of three to five times better than the lidar points.

Absolute Accuracy: Expect 0.03 meters horizontal and 0.05 meters vertical at 95% level of confidence relative to the constraints introduced in the adjustments. .

QAQC ANALYSIS- Not included here, see Dewberry & Davis for analysis

NGS STATIONS and CORS DESCRIPTIONS (see attached file)

SURVEYOR'S STATEMENT

This Report on the criteria and procedures used on this QAQC Survey was prepared by me or under my direction May 5, 2005 for the purpose of validating the lidar acquired Digital Elevation Model (DEM) at the request of Dewberry & Davis Inc.

Michael R. McGee, CA PLS 3945